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Theory to Practice: Application of Problem-based learning, Flipped-classroom, and Just-in-time-teaching in an Advanced Geotechnical Engineering Course

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INTRODUCTION

Geotechnical engineering, more than most other engineering disciplines, is highly empirical and experientially based due to the nature of geological settings and the resulting multitude of variables and uncertainties. Engineering education can be viewed in a similar manner. Both disciplines have their theories, yet due to the uncertainties in both geological and behavioral sciences, it is not until the theories are put to practice and the results carefully observed that understanding develops. As geotechnical legend Dr. Ralph Peck once stated, "No theory can be considered satisfactory until it has been adequately checked by actual observations." Following this thought, the Fall 2020 and 2021 Advanced Soil Mechanics and Foundation Engineering course taught at the United States Military Academy was redesigned to put both geotechnical engineering and pedagogical theory into practice. Teams of students were presented real-world geotechnical engineering challenges from around the campus and then asked to solve the problems as a consulting firm would. While students were busy putting geotechnical engineering theory into practice, their efforts were supported by a course designed as a problem-based, flipped-classroom, with just-in-time-teaching, thereby combining and putting modern pedagogical theory into practice. This paper presents the evidence-based practice study of interleaving and putting the pedagogical theories of problem-based learning, flipped classrooms, and just-in-time-teaching into practice. It captures the intricacies of the course design, documents the student and professor experience, and provides analysis and recommendations for engineering educators aimed at supporting the jump from theory to practice for these educational methods. This paper also demonstrates both the synergies and challenges experienced when interleaving these pedagogies together. Finally, this paper demonstrates how the course design successfully contributed to student learning and inspiration, while also addressing all seven of ABET's student outcomes. This paper will be of interest to educators looking to incorporate these pedagogies, especially when attempting to interleave them together.

THEORY

Problem-Based Learning

"Problem-based learning (PBL) is a student-centered approach in which students learn about a subject by working in groups to solve an open-ended problem. This problem is what drives the motivation and the learning." [1] It was first championed in a medical program at McMaster University in the late 1960's with the following characteristics:

1. Learning is student centered.
2. Learning occurs in small student groups
3. Teachers are facilitators or guides
4. Problems form the organizational focus and stimulus of learning
5. Problems are the vehicles for the development of problem-solving skills
6. New information is acquired through self-directed learning. [2]

Since its introduction, an explosion of research touts the pedagogy and its effectiveness. As with many pedagogical methods, the effectiveness depends on the how the theory is put into practice, and as Graaf points out “the label ‘PBL’ is used to cover an amazing diversity of educational practices, ranging from problem-oriented lectures to completely open experiential learning environments aimed at improving interpersonal relations.” [3] Despite the diversity of applications, a review of the literature suggests that problem-based learning enhances the transfer of concepts to new problems, integration of concepts, intrinsic interest in learning, self-directed learning, and earning skills. [4]

Flipped Classroom

In its most basic form, “inverting the classroom means that events that have traditionally taken place *inside* the classroom now take place *outside* the classroom and vice versa.” [5] However, in practice, the *flipped classroom* encompasses more than rearranging the content offering, it includes, and requires, an integration of well-planned learning activities. [6] As such, Bishop and Verleger suggest a more refined definition of a flipped classroom: “an educational technique that consists of two parts: interactive group learning activities inside the classroom, and direct computer-based individual instruction outside the classroom.” [6] This two-part definition is reiterated by Felder and Brent, who claim “effective classroom flipping has two components: *interactive online presentation of information before class* and *well-implemented active learning in class*. [7] Felder and Brent go on to provide suggestions on how to successfully implement a flipped classroom, but do not offer examples of flipped classrooms. Other more useful sources for implementing the flipped classroom theory can be found on websites such as Harvard’s Universities Flipping Kit [8] and the *Flipped Classroom Field Guide*. [9] The *Flipped Classroom Field Guide* proposes the following four “Golden Rules of Flipping:”

1. *The in-class activities involve a significant amount of quizzing, problem solving and other active learning activities, forcing students to retrieve, apply, and/or extend the material learned outside of class. These activities should explicitly use, but not merely repeat, the material in the out-of- class work.*
2. *Students are provided with real-time feedback.*

3. *Completion of work outside class and participation in the in-class activities are worth a small but significant amount of student grades. There are clear expectations for students to complete out-of-class work and attend in-person meetings.*
4. *The in-class learning environments are highly structured and well-planned.* [9]

Multiple studies have suggested that the flipped classroom can result in significant learning gains. Vanderbilt University's Center for Teaching website presents several studies backing the flipped pedagogy. [10] More recently, Strelan et al. conducted a meta-analysis on the topic in 2020, examining 198 studies, concluding the flipped classroom has a moderate positive effect ($g = .50$) on student performance and was beneficial regardless of discipline. [11]

Just-in-Time-Teaching

The just-in-time teaching pedagogy is essentially the observational method used by geotechnical engineering legends Karl Terzaghi and Ralph Peck applied to education. "Just-in-Time Teaching (JiTT) is a technique where students are expected to do a pre-class activity, submit responses to this activity, and then the instructor uses these responses to tailor class to the specific needs of the students." [12] It was first introduced in the 1990s and like the previously discussed pedagogies, can take varying forms and have varying degrees of effectiveness in practice. Despite the diversity, the pedagogy has shown to increase retention, process skills, and context knowledge. [12]

PRACTICE

CE472 and the Course Setting

CE472: Advanced Soil Mechanics and Foundation Engineering is a three-credit engineering elective offered within the Civil and Mechanical Engineering Department at the United States Military Academy. The course catalog states:

> *Students will extend what they learned in Soil Mechanics and Foundation Engineering and design advanced foundations in this course. Topics covered are: slope stability, field testing, field instrumentation, designing braced excavations, designing piles and drilled shafts, designing flexible walls, designing earth retaining structures, and designing earth structures using geosynthetics*. [13]

The course has been taught for fourteen years by various instructors and in various formats. In the fall of 2020, the course included seventeen undergraduate seniors and consisted of thirty 75-minute lessons. In the fall of 2021, the course included twelve undergraduate seniors and again consisted of thirty 75-minute lessons. The course objectives were:

1. *Apply* the fundamental principles of soil mechanics and foundation engineering to *solve* geotechnical engineering problems.
2. *Apply* the engineering design process to *design* solutions to geotechnical engineering problems.
3. *Communicate* and *justify* engineering design through oral and written form.
4. *Function* as part of a team.

When examining the pedagogies described in the remainder of this paper, it is important to keep in mind that this course was an elective undergraduate senior level (i.e. 400 level) course. While the 29 students represented in the study's population had varying incoming GPAs ranging from 2.48/4.33 to 3.88/4.33, they were mature students who had just completed their required soil mechanics course in the previous semester, and voluntarily chose to take the elective presumably out of interest. Additionally, the instructor had three years of experience teaching undergraduates, had experienced four semesters of problem-based learning in senior capstone courses, two semesters of a flipped classroom in a mechanics of materials course, but had no previous experience with just-in-time teaching. Finally, while this course was taught in the middle of the COVID-19 pandemic, it is important to note that it was conducted in-person. The United States Military Academy implemented strict policies to protect the health and safety of the community, thereby making it possible to meet in-person and to nearly conduct the course as if under normal conditions.

Setting Expectations

As undergraduate seniors, the students were primarily familiar with traditional pedagogies – receiving new material in class and working on a homework out of class. To set conditions for implementing the three pedagogies examined in this study, students were made aware of the course design via a two-page description in the syllabus, a question on the first homework assignment asking the students to describe the course in their own words, and through repeated verbal reminders by the instructor throughout the semester.

Problem-Based Learning

Two versions of problem-based learning were implemented in the course – daily homework problems, and large real-world problems.

Homework Problems

Homework problems are not typically thought of as problem-based learning; however, homework problems in this course were presented in such a way as to contribute to four of the six problem-based learning characteristics as described by [2]:

1. ✓ Learning is student centered.

2. ✗ ~~Learning occurs in small student groups~~
3. ✗ ~~Teachers are facilitators or guides~~
4. ✓ Problems form the organizational focus and stimulus of learning
5. ✓ Problems are the vehicles for the development of problem-solving skills
6. ✓ New information is acquired through self-directed learning.

First, the homeworks were individual assignments, contributing to being student centered. Second, inspired by a blog post [14] titled *Learning Objectives vs Learning Questions*, the homework questions directly served as the organizational focus and stimulus of learning. While learning objectives were provided to students for each lesson, they were broad statements whose purpose was to show how the lesson fit within the course; it was the homework questions themselves that truly provided the structure. As [14] states, "learning questions aim to make us curious" and "might be more activating to the learner as they can stimulate learners to think about possible answers, or possible ways to reach the desired learning outcome." Third, inspired by [15] paper titled *Daily Fundamentals – Your Daily Dose of Mechanics Exercises*, the homeworks presented consistent micro-moments to develop problem solving skills. Finally, the questions themselves required students to seek out new information, thereby contributing to the concept of self-directed learning.

The thirty homeworks associated with the thirty lessons generally consisted of six to ten questions that encouraged the students to engage with the material in the following topics:

1. *The real-world problem the students were solving in groups* – these problems encouraged the students to research the project and perform individual actions that would contribute to the group effort in the following in-class experience.
2. *Fundamental geotechnical engineering concepts* – these problems were review problems to reinforce the fundamental concepts.
3. *Design process* – these problems encouraged the students to apply the engineering design process to the real-world problem they were solving in groups.
4. *Teamwork* – these problems encouraged students to read Harvard Business Review articles on teamwork and apply the concepts to their group project.
5. *New Knowledge* – these problems encouraged students to increase their depth of understanding of soil mechanics and foundation engineering.
6. *Technical communication* – these problems asked the students to read a page of the department's technical communications guide and reflect on how they could incorporate the concepts into their group report and presentation.
7. *Wisdom* – these questions presented a quotation from Dr. Ralph Peck and asked the students to interpret and explain the quotation.

Each homework was designed to take 75 minutes to complete and was worth 10 points each in the 2,000-point course. Homeworks were provided through the course's Microsoft Team site using the assignments function and Microsoft OneNote integration feature. This enabled students to open Microsoft OneNote on their devices and complete the homework within the app.

Real-World Problems

The second implementation of problem-based learning in the course took the form of two large real-world problems. Students were placed into groups of four to five, were given the scenario, a large quantity of information about the project, and were asked to solve the problem concluding in a final presentation and formal report. The selected scenarios were real-world geotechnical engineering projects within walking distance from the classroom. Project information and geotechnical investigation reports were graciously provided by the U.S. Army Corps of Engineers, who managed both real-world projects. The first project was an earthen embankment dam that had been drained due to seepage concerns. Students were provided a geotechnical investigation report of the dam (with a few parts redacted by the instructor) and were asked to design a retrofit solution to make the dam functional again. The second project required students to design micropiles for the foundation of the columbarium in an on-going cemetery expansion project. Students were given nearly 2,000 pages of technical information about the entire cemetery expansion project (with all the micropile design elements redacted by the instructor). These group design challenges contributed to all six problem-based learning characteristics as described by [2]:

1. ✓ Learning is student centered.
2. ✓ Learning occurs in small student groups
3. ✓ Teachers are facilitators or guides
4. ✓ Problems form the organizational focus and stimulus of learning
5. ✓ Problems are the vehicles for the development of problem-solving skills
6. ✓ New information is acquired through self-directed learning.

Flipped Classroom

In an attempt to make the flipped classroom pedagogy successful, the previously discussed "flipping kit" from [8] was utilized, which supported the "Golden Rules of Flipping."

The first "golden rule" states *The in-class activities involve a significant amount of quizzing, problem solving and other active learning activities, forcing students to retrieve, apply, and/or extend the material learned outside of class. These activities should explicitly use, but not merely repeat, the material in the out-of- class work.* [9] In-class activities consisted of a homework review if necessary, followed by an activity that enabled the student teams to make progress on their group project. For example, early in both projects, for homework, the students were asked to individually find how many borings were conducted in the geotechnical exploration and approximately how many different soil types were encountered. This enabled each student to be prepared to work with their team in class to interpret the data and draw the soil profile along a given cross-section. This was one of the most effective in-class activities as it generated a significant amount of debate between the students as they compared their individual homework findings and worked to combine those into a group product. In this way, this in-class activity explicitly used the out-of-class material but did not repeat it. In addition to the in-class activity, as the students worked with their groups, the instructor would float around and ask probing questions to guide the students and to informally assess their understanding.

The second "golden rule" states *students are provided with real-time feedback.* [9] Using the just-in-time teaching pedagogy, along with using Microsoft Teams and Microsoft OneNote, it was possible for near real-time feedback. Students were able to enter class with their homework already graded, and the instructor was able to start class with a tailored review to address homework issues. Additionally, as the students worked with their teams, the instructor would float around the classroom and provide real-time feedback to keep the teams moving in the right direction in an efficient manner.

The third "golden rule" states *completion of work outside class and participation in the in-class activities are worth a small but significant amount of student grades. There are clear expectations for students to complete out-of-class work and attend in-person meetings.* [9] The thirty homeworks were worth ten points each, making up fifteen percent of the overall course grade. In-class activities did not have points directly attached to them, but each group project culminated in a 50-point presentation, a 250-point report, and a peer evaluation which was generated an individual factor that applied to each individual's grade. It was hypothesized that the combination of peer pressure and a high-stakes report would encourage the students to participate in-class.

The fourth "golden rule" states *the in-class learning environments are highly structured and well-planned.* [9] While designing the course, the instructor created a spreadsheet where each row was a lesson, and each column contained details of both the out-of-class and the in-class assignments. This spreadsheet enabled the generation of a highly structured and well-planned course where the out-of-class homeworks directly supported the in-class activities. Additionally, to help the students see the structure and make the connections between their homeworks and in-class work, each homework also contained an outline preview of what the in-class time would look like.

Just-in-Time Teaching

Just-in-Time Teaching was accomplished with homework assignments that were submitted via Microsoft Teams and Microsoft OneNote at midnight prior to class, thereby enabling the instructor to grade them and provide feedback before the start of class. This allowed the students to see the feedback they needed to successfully contribute to their in-class group activities, while also allowing the instructor to tailor the start of class review to address any issues.

ASSESSMENT & DISCUSSION

Assessment of the course included a midterm reflection question on a homework assignment, comments students would make in short answer questions on homeworks, comments provided in the Comprehensive Assessment of Team Member Effectiveness (CATME) peer assessment tool (www.catme.org), student grades, a time survey, and an anonymous end of course survey.

Midterm Reflection

Following the midterm exam, students were asked to provide a non-anonymous paragraph discussing their reflections on the course and specifically identify any sustains and improves. In general, student responses were extremely positive. Students stated they most enjoyed working on a real-world and relevant problem that, unlike most of their academic experience, did not have a single correct answer. Related, students appreciated being able to walk to the site and conduct a physical reconnaissance so they could personally see what they were reading about in the report. The second most commented aspect of the course was the group work; students expressed a strong desire to work in groups. This may be unique to the course as it is a senior level elective, implying mature students who chose to take the course out of interest. The remaining positive comments varied with regard to topic, but in general, demonstrated an appreciation for the connections between the homework and the in-class work and the overall structure of the course. As with any assessment, the students also identified aspects of the course they would like to see improved. The most requested improvement called for the group design report to include graded draft submissions and progress-review meetings with the instructor. Students expressed concern about the high stakes report and wanted to know if they were on the right track. The second most repeated improvement requested more instructor guidance to help students wade through the 200+ pages of technical material provided to them for each project. This comment was repeated in various ways, generally expressing a theme of struggling to practice self-directed learning. The third most repeated improvement was to change the homework due time from midnight to the morning of class. Finally, there were a handful of comments from students indicating they would prefer some traditional lessons where the instructor provided new content in class and the students took notes.

Homework Questions

Throughout the semester, many of the homework questions were short answer and asked the students to reflect or provide their thoughts on a given prompt. The instructor observed a general appreciation for including questions related to teamwork, technical communication, and interpreting Dr. Ralph Peck's quotations. Students seemed to easily recognize the importance of teamwork and communication and frequently made comments in their homework stating, "I wish

I had been taught this years ago." The Dr. Ralph Peck quotations became a source of levity for the students as they enjoyed applying the quotations in various contexts throughout the course.

Comprehensive Assessment of Team Member Effectiveness (CATME) Surveys

At the end of each group project, students were asked to complete a CATME peer assessment survey (www.catme.org), the results of which the instructor used to inform the peer assessment grade for each student. While this tool did not directly assess the course, it did provide feedback on the implementation of teamwork into the course. For the first project in the fall of 2020, groups were assigned based only on student performance in the prerequisite soil mechanics course. The instructor attempted to balance each group. The CATME results for the first project indicate that some students did not perform well in their assigned teams. Taking this, and some of the midterm reflection feedback into consideration, the students were able to provide some input into the formation of teams for the second project in the fall of 2020. Each student was asked to provide the name of someone they would like to work with, and someone they would prefer not to work with. The instructor used this information to generate teams for the second project, which produced better CATME peer assessments, but interestingly, for half the groups, lower quality reports and presentations. In the fall of 2021, groups were again assigned based only on student performance in the prerequisite soil mechanics course.

Student Performance and Time Survey

The course outgoing GPA was a 3.72/4.33 in 2020 and 3.61/4.33 in 2021, which is higher than the course ten-year average of a 3.49/4.33 outgoing GPA. It is unclear if the newly incorporated pedagogies contributed to this increase or if other factors influenced student performance. However, there is a correlation with the increased performance and increase in the amount of time students reported having spent outside of class working on the course material. The last question of every homework assignment asked students to report how much time they spent completing the homework and preparing for the next class. Students reported spending an average of 89 minutes per lesson outside of class in 2020, and 70 minutes in 2021; both of which are higher than the ten-year course average of 63 minutes. Considering [16] findings that there is a "positive relationship between time-on-task and student achievement," it may be possible that the course design encouraged higher performance simply by encouraging more "time-on-task."

End of Course Feedback

The course end survey results indicate students appreciated the course. To use their own words:

> *The course was well planned and had the intended effect. I believe it was important to have this course because it made me put into application what I had learned in CE371 the previous semester. It was instrumental in having me critically think over real life*

problems to provide the best possible solution. This class hit the mark, I felt like it had a purpose unlike some classes I took.

I thoroughly enjoyed the structure of the course and the challenge of learning the material before class and applying it to real world engineering problems.

I really liked the format of using real world projects for new topics.

I really enjoyed this course. As the final course in the CME Department that I will take before graduating, it was fantastic. The course and instructor opened my mind and peaked my interest in the realm of Civil Engineering. I was grateful to be accepted into this elective.

Good course. Definitely emphasized critical thinking.

SUMMARY OF FINDINGS & RECOMMENDATIONS

While the assessments do not definitively indicate the effectiveness of the applied pedagogies, the data does suggest the methods used to apply the pedagogies successfully contributed to student learning and inspiration, while also addressing all seven ABET student outcomes. The 2021 anonymous course end feedback survey asked the students the seven ABET student outcomes in the form of Likert questions (1 being "strongly disagree," and 5 being "strongly agree"):

1. This course improved my ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics (mean = 4.6, median = 5)
2. This course improved my ability to apply engineering design to produce solutions that meet specified needs. (mean = 4.3, median = 4)
3. This course improved my ability to communicate effectively with a range of audiences. (mean = 4.5, median = 4.5)
4. This course improved my ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements. (mean = 4.3, median = 4)
5. This course improved my ability to function effectively on a team. (mean = 4.6, median = 5)
6. This course improved my ability to analyze and interpret data and use engineering judgement to draw conclusions. (mean = 4.3, median = 4)
7. This course improved my ability to acquire and apply new knowledge as needed, using appropriate learning strategies. (mean = 4.5, median = 4.5) [17]

Setting Expectations

For educators looking to implement new pedagogies in their courses, it is recommended both the description and purpose of the pedagogy are shared with the students. It is also recommended the students be asked to provide a back-brief of their understanding of the new pedagogy and how they may need to adapt their studies to the new structure. The combination of statements in the syllabus, early homework questions, and verbal in-class re-iteration was found to be successful in this course.

Problem-Based Learning

The key to making problem-based learning successful was found to be obtaining relevant and real-world problems to analyze. The problems should be relevant to the students to help generate excitement. A suggested method to identify relevant topics is to find projects within walking distance of the classroom, or to identify projects that have local significance. If no current projects exist, there may be records for the local existing infrastructure. The problems should also be real world. This means the information provided to students must come from actual project sources, not instructor generated givens and references. The two design problems analyzed in this course were made possible by the U.S. Army Corps of Engineers graciously providing design reports and calculations. Geotechnical professionals working on projects near academic institutions could provide a combination of project background, a geotechnical investigation report, and design calculations. The design calculations are extremely valuable to the instructor as they provide a possible solution and enable the instructor to focus on course development rather than practicing engineering and solving the problem. Even with provided calculations, the educator should plan to spend a significant amount of time familiarizing themselves with the projects in order to address student questions and to redact portions that would jeopardize the learning value for the students. For the two projects used in this course the instructor spent a substantial amount of time over the summer reviewing project documents, replicating the finite-element seepage analyses, and reconning the two projects to be prepared for the course. While this was a large initial time cost, it paid off in the fall of 2021 when reusing the course material.

In implementing problem-based learning, it is recommended the educator provide all the information up front despite the overwhelming feeling students may feel when confronting it. There is immense learning value to the student in being required to sift through actual engineering documents and become familiar with their language and structure. However, as stated above, managing expectations is critical. It is recommended students be made aware of why the project information is being presented in its raw form. Additionally, when implementing problem-based learning, the educator should spend time critically designing the course so that the problem and student work support the course learning objectives. A way to do this is to build a spreadsheet matrix where each row is a lesson, and each column contains details of how the out-of-class and in-class activities will support learning objectives. It is critical to include details for both out-of-class and in-class activities, even if the course is not utilizing the flipped classroom pedagogy. Teamwork is another important aspect of the problem-based pedagogy that the educator must thoroughly consider. It is recommended the educator spend time researching team formation strategies and critically consider the course teamwork goals. Randomly assigning teams may be appropriate or it may not depending on the course goals. Having students work with their friends, as was done with the second project in 2020, may result in a more enjoyable experience, but not necessarily the best learning experience. Therefore, the educator must critically assess the purpose for teamwork in their course. As was done in this course, it is also recommended that the educator build in activities to develop teamwork skills. If teamwork in a technical context is an ABET, program, and course goal, it follows that the course should include content that develops the skill beyond throwing the students into teams and being told to work as a team. A suggested way to develop team skills is to utilize the institution's library and obtain Harvard Business Review (HBR) articles about teamwork and include these as part of the course reference material. HBR articles are relatively short and always contain clear summaries, thereby making them relatively low time-demand readings for students to respond to. Finally, when implementing problem-based learning, it is recommended the educator incorporate formal progress reviews to ensure the students are on track and help address their concerns.

Flipped Classroom

When implementing the flipped classroom pedagogy, it is recommended the educator thoroughly study the literature and follow 'flipping guides' such as Harvard's University's Flipping Kit [8] and the *Flipped Classroom Field Guide*. [9] Additionally, as the *Flipped Classroom Field Guide* discusses, a flipped classroom requires a high degree of instructor involvement. An educator wanting to implement a successful flipped classroom should expect to spend time carefully developing the course so out-of-class activities directly support in-class activities and vice versa, and then still expect to be fully present and engaged during in-class time. The educator may also find the in-class time to be more mentally engaging than traditional pedagogies as the educator may confront varying questions from individual students that require the educator to juggle multiple concepts within one class period. Finally, based on the experiences and student feedback in this course in the fall of 2020, it is recommended that difficult concepts needed for the projects still be taught using traditional instructor led board work and lecture to facilitate the transfer of challenging knowledge using familiar methods.

Just-in-Time-Teaching

Similar to the flipped classroom pedagogy, just-in-time teaching also requires a high degree of instructor involvement. In fact, the *Flipped Classroom Field Guide* also discusses this. However, as was found in teaching this course in the fall of 2020, if the instructor is already willing and able to put time and energy toward flipping a course, the just-in-time teaching pedagogy complements the course without adding additional demands on the instructor. For educators looking to practice the just-in-time pedagogy, it is also recommended that float be built into the course schedule to accommodate changes based on homework or quiz results. Additionally, similar to how geotechnical engineering legend Ralph Peck identified that the observational method does have limitations and drawbacks, so does the just-in-time pedagogy. The educator would be wise to take heed of Peck's advice:

There is no doubt that the full value of the method cannot be realized unless the [educator] is thoroughly conversant with his [/her students], makes continuous alterations of designs and procedures and the information is obtained and has the authority to act quickly upon his[/her] decisions and conclusions. [18]

Finally, in implementing the just-in-time teaching pedagogy, it is recommended the educator simply block off one to two hours prior to each class to review the homework or quiz submissions and alter the lesson plan as necessary. It is recommended this be the two hours prior to the class and that the homeworks or quizzes be due at the start of this time, thereby giving the students the maximum amount of time possible to submit their responses.

LIMITATIONS

This paper presented the evidence-based practice study of applying the pedagogical theories of problem-based learning, flipped classrooms, and just-in-time-teaching. It is acknowledged that the population size was small, that there was no control group, and that unique nuances exist at the institution that impacted the conduct of the course compared to the conduct of courses at other institutions. Despite this, the purpose of the study was not to prove or disprove each pedagogy, but to capture and provide analysis and recommendations for engineering educators aimed at supporting the jump from theory to practice for these educational methods. The exact conditions and implementations of the three pedagogies in this study may not work at other institutions, but it is hoped the details will help others be successful in their idiosyncratic implementations of theory to practice.

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